Fits to HERA combined F_2 (charm) data

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Heavy Quark Flavour Number Schemes matter when fitting F_2(charm) data

The fits are sensitive to value of the charm mass m_c

NLO fits have been made using:

General Mass Variable Flavour Number Schemes

RT- Standard (as for MSTW08), RT-Optimized (see talk of Thorne in HF session), ACOT full (as for CTEQ)

Fixed Flavour Number Scheme

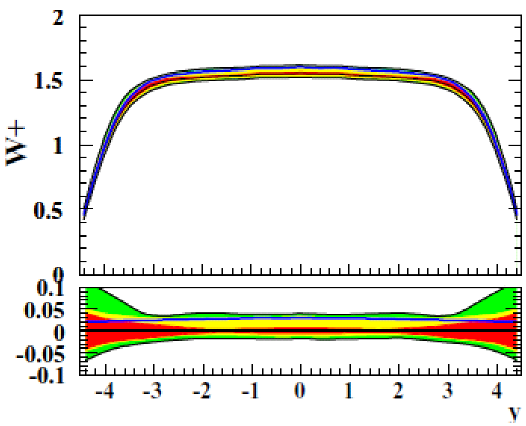
NNLO fits have been made using

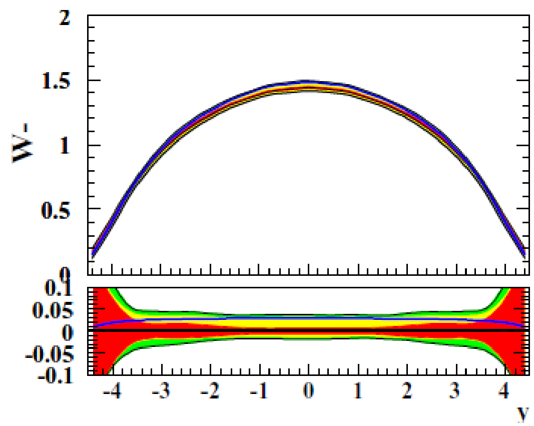
RT-Standard (as for MSTW08)

PDF fits use various Heavy Quark Schemes and most use a value of the charm mass m_c=1.4 GeV, however the pole mass is m_c=1.65 GeV. Inclusive data are insensitive to these choices BUT

there is an important consequence of the choice of the charm mass –the choice of the pole mass raises W/Z cross-section predictions at the LHC by ~3%

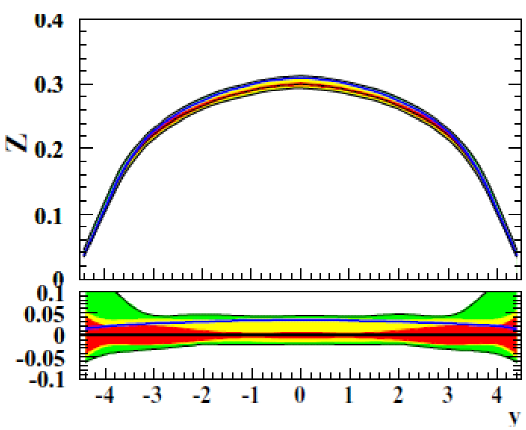
W and Z rapidity distributions





Predictions from HERAPDF1.0 for W+ W- and Z rapidity distributions at the LHC 14 TeV (m_c=1.4GeV)

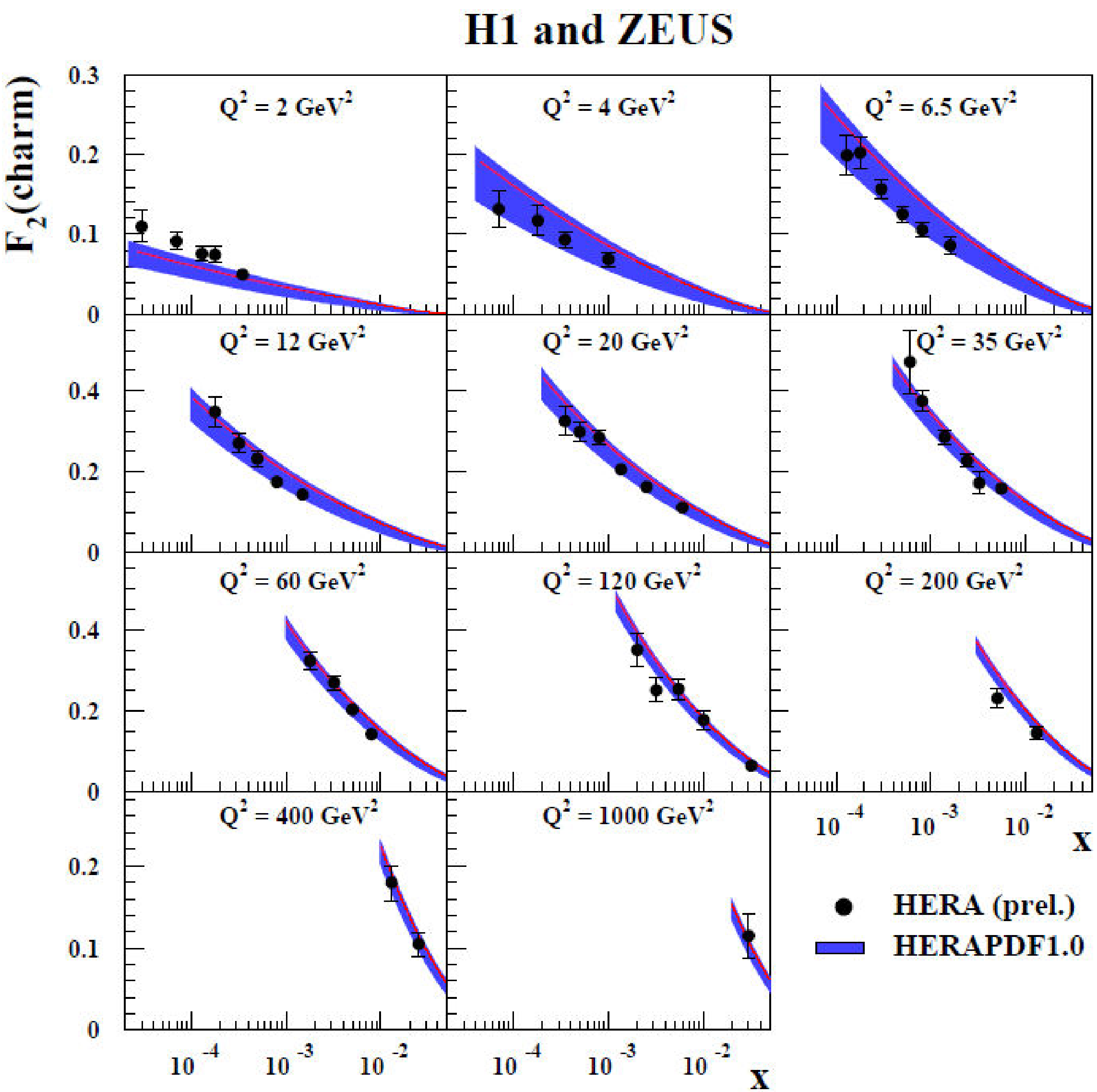
The blue line shows the shift for m_c=1.65 GeV



$\sigma(W^{+}).B_{W\to l\nu}$ (nb)	$\sigma(W^{-}).B_{W\to l\nu}$ (nb)	$\sigma(Z).B_{Z\to ll}$ (nb)
m_c=1.4 GeV		
12.44±0.01	9.28±0.05	2.076±0.014
+0.31 -0.08	+0.25 -0.07	+0.059 -0.015
+0.23 -0.06	+0.21 -0.04	+0.045 -0.009
m_c=1.65 GeV		
12.76	9.52	2.13

Compare HERAPDF1.0 to HERA combined F^2(charm) data

Charm data are sensitive to the choice of the charm mass



In the published HERAPDF1.0 fit the charm mass varies between m_c=1.35 GeV (top of error band) and m_c=1.65 GeV (bottom of error band)

The central HERAPDF1.0 fit used m_c=1.4 GeV

Now try fitting the F_2(charm) data

The published HERAPDF1.0 fits were done with the STANDARD RT-VFN formalism – as used by MSTW08

However, Thorne has subsequently shown alternative versions of the VFN scheme with somewhat different threshold behaviours. We have also tried the version which has a smoother threshold behaviour- which I will call OPTIMIZED RT-VFN- shown as GMVFNSopt These schemes are all equally valid.

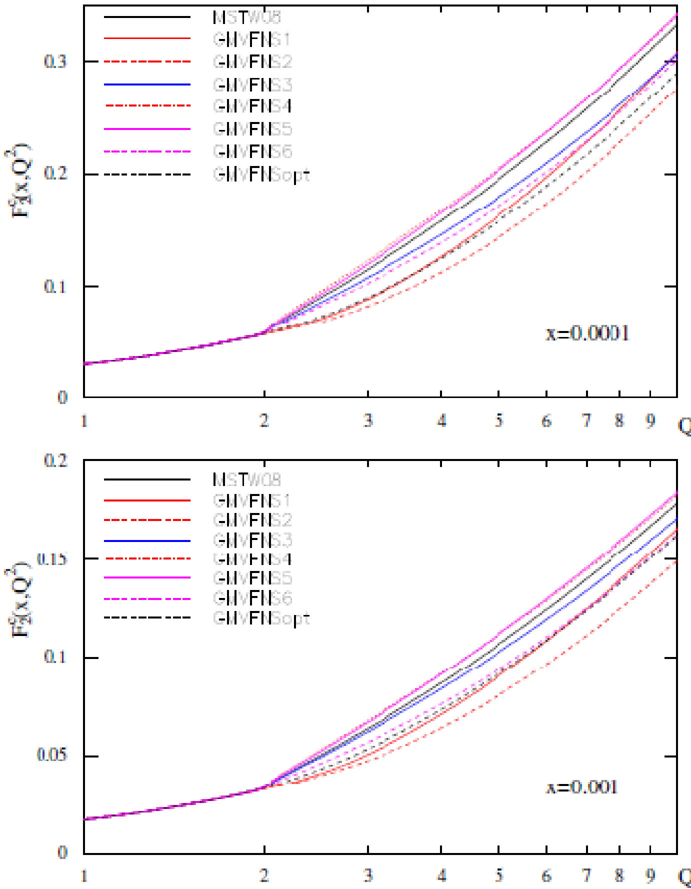
In both cases Q^2 is the renormalisation and factorisation scale for light and heavy quarks as appropriate to these schemes

We use the usual cuts on data $Q^2 > 3.5$ GeV^2, so 41 F_2^c data points are fitted

The formalism is the same as for HERAPDF1.0 unless otherwise stated

We compare two values of charm mass

m_c=1.4 GeV and m_c=1.65 GeV

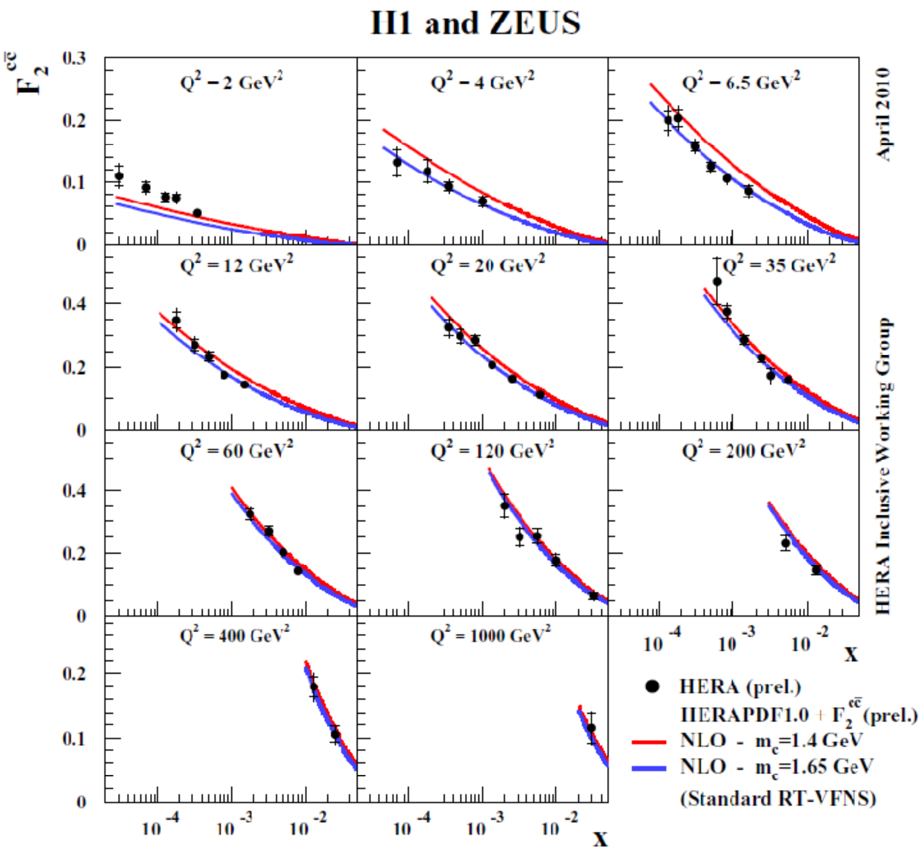


Various GM VFNS as considered by Thorne PDF4LHC meeting Oct23rd 2009

Fits to HERA-I +F_2(charm) data using STANDARD RT VFN scheme

m_c=1.4 in red- very close to HERAPDF1.0

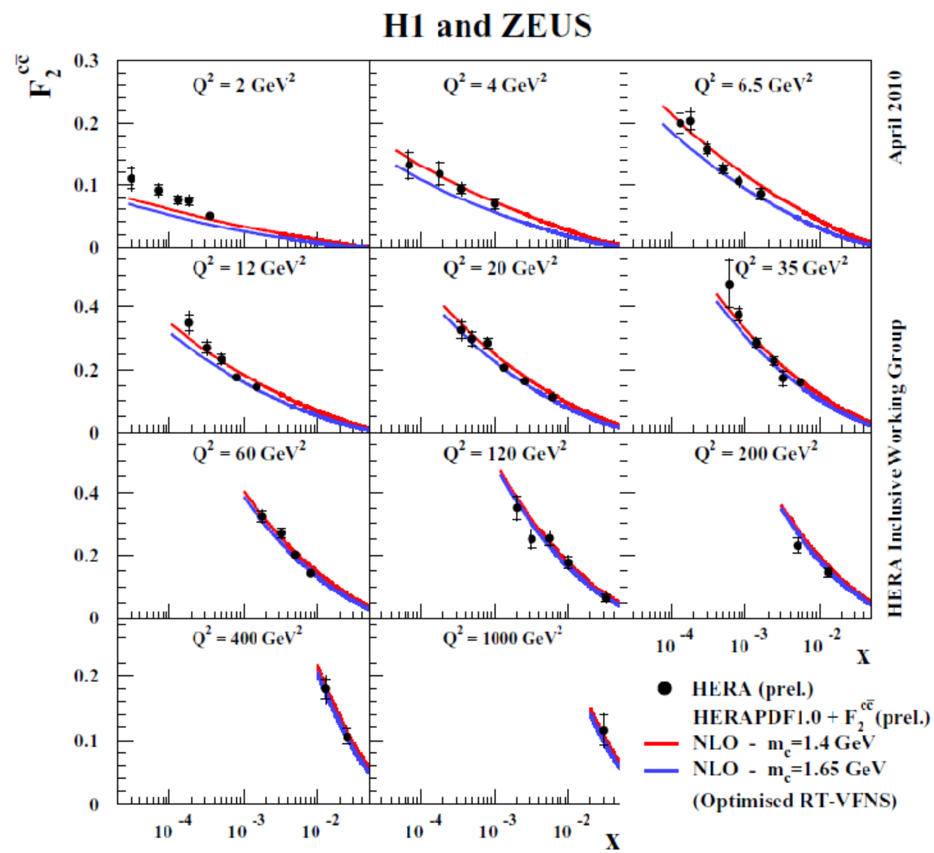
m_c=1.65 in blue– the data prefer this fit



Fits to HERA-I +F_2(charm) data using OPTIMIZED RT VFN scheme

m_c=1.4 in red- the data prefer this fit

m_c=1.65 in blue



Note that the behaviour of OPTIMIZED RT VFN at threshold is smoother

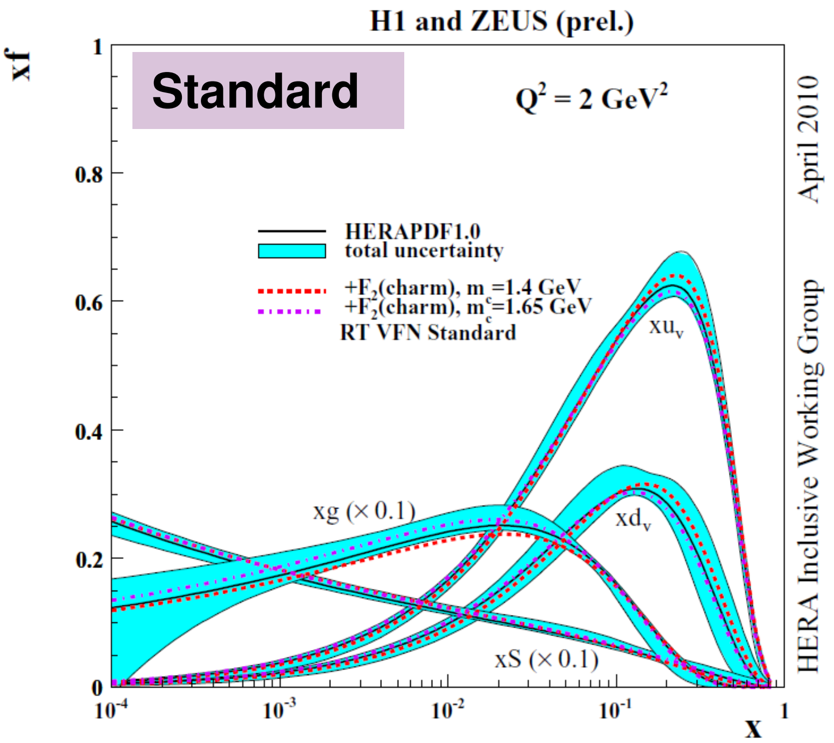
OPTIMIZED RT VFN is relatively suppressed- thus a higher value of m_c is not needed to suppress the F2(charm) predictions

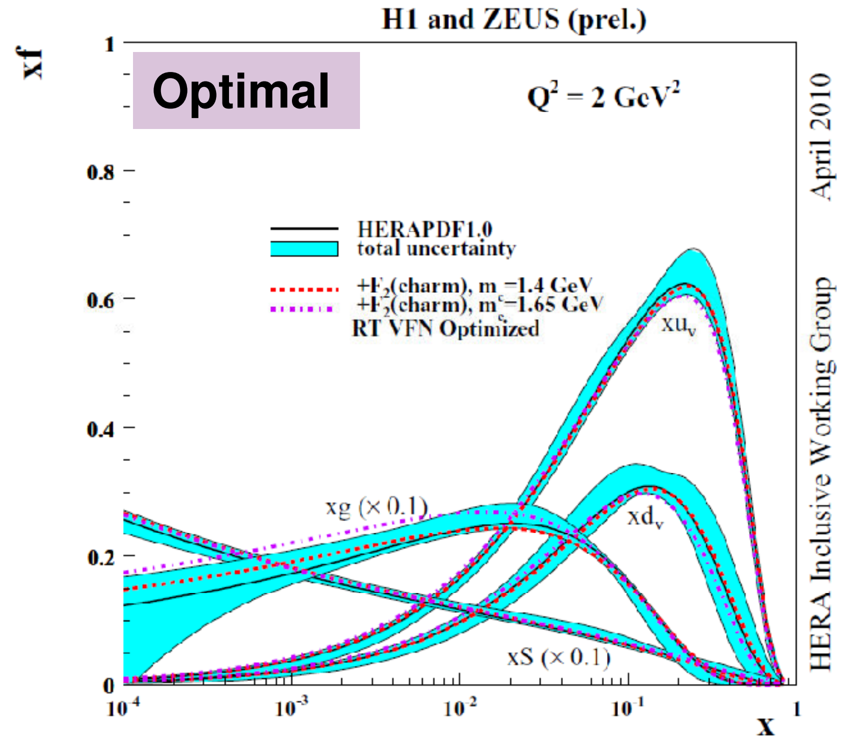
$\chi 2$ for the F_2(charm) data is MUCH better for mc=1.65 for RT VFN Standard

$\chi 2$ for the F2(charm) data is MUCH better for mc=1.4 for RT VFN Optimized

scheme	RT Std m_c=1.4	RT Std m_c=1.65	RT Opt m_c=1.4	RT Opt m_c=1.65	#points
Total $\chi 2$	**730.7**	**627.5**	**644.6**	**695.4**	633
$F_2^{(charm)}$ sub $\chi 2$	134.5	43.5	64.8	100.1	41

Now compare the PDFs for the Standard and Optimal RT VFN Schemes





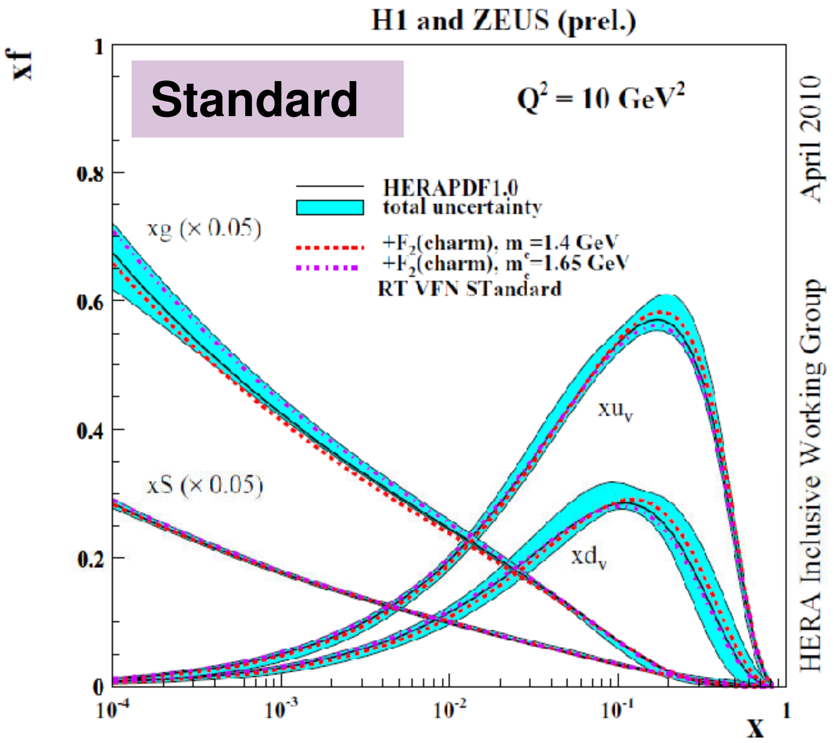
At the starting scale, with mc=1.4 GeV and mc=1.65 GeV

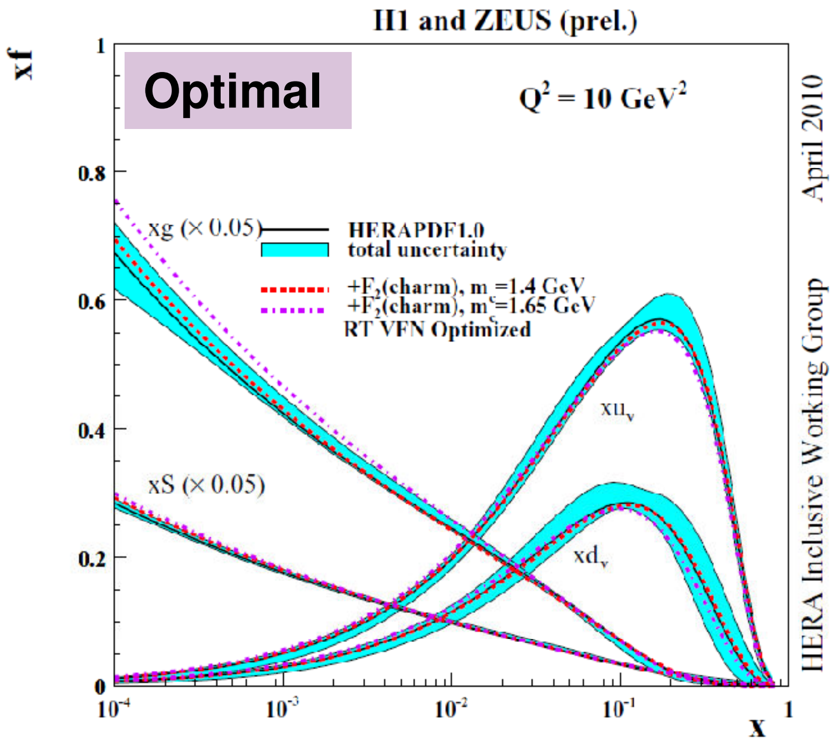
Higher charm mass gives suppressed F_2(charm) but enhanced gluon at low-x

The Optimal scheme has slightly more low-x gluon than the Standard scheme

However in general the PDFs are not very different for these two schemes and two values of the charm mass

Now compare the PDFs for the Standard and Optimal RT VFN Schemes





At Q^2 =10 GeV^2, with mc=1.4 GeV and mc=1.65 GeV

Higher charm mass gives suppressed F_2(charm) but enhanced gluon at low-x

The Optimal scheme has slightly more low-x gluon than the Standard scheme

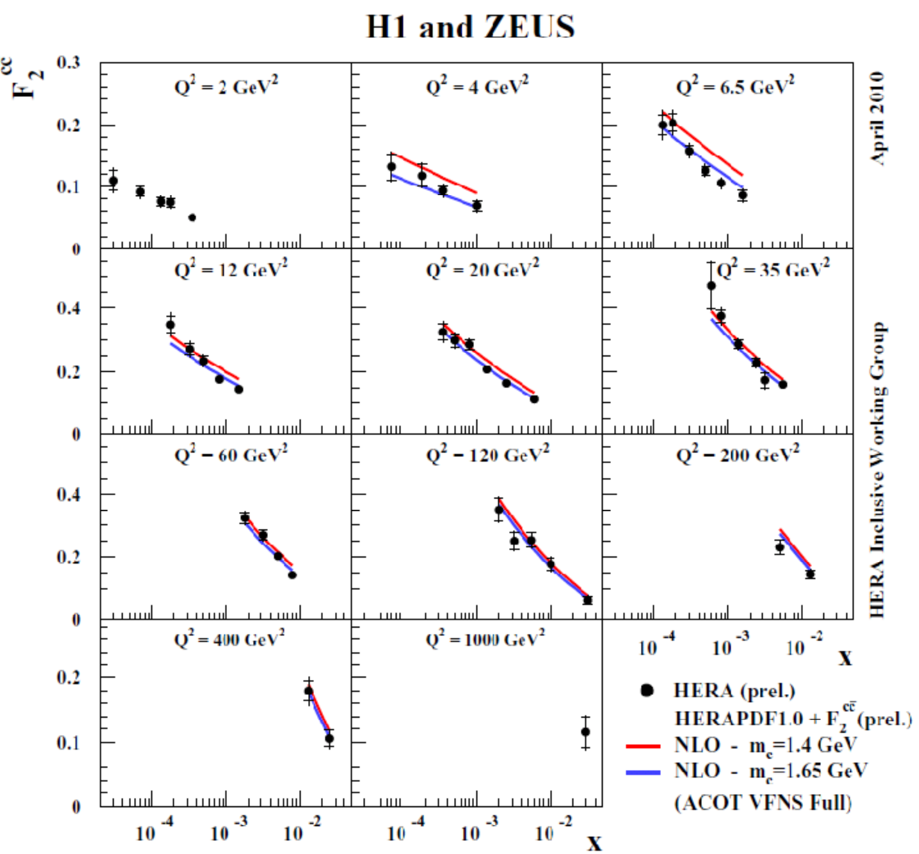
However in general the PDFs are not very different for these two schemes and two values of the charm mass

For the published HERAPDF1.0 we also **compared ACOT VFN to RT VFN Standard**

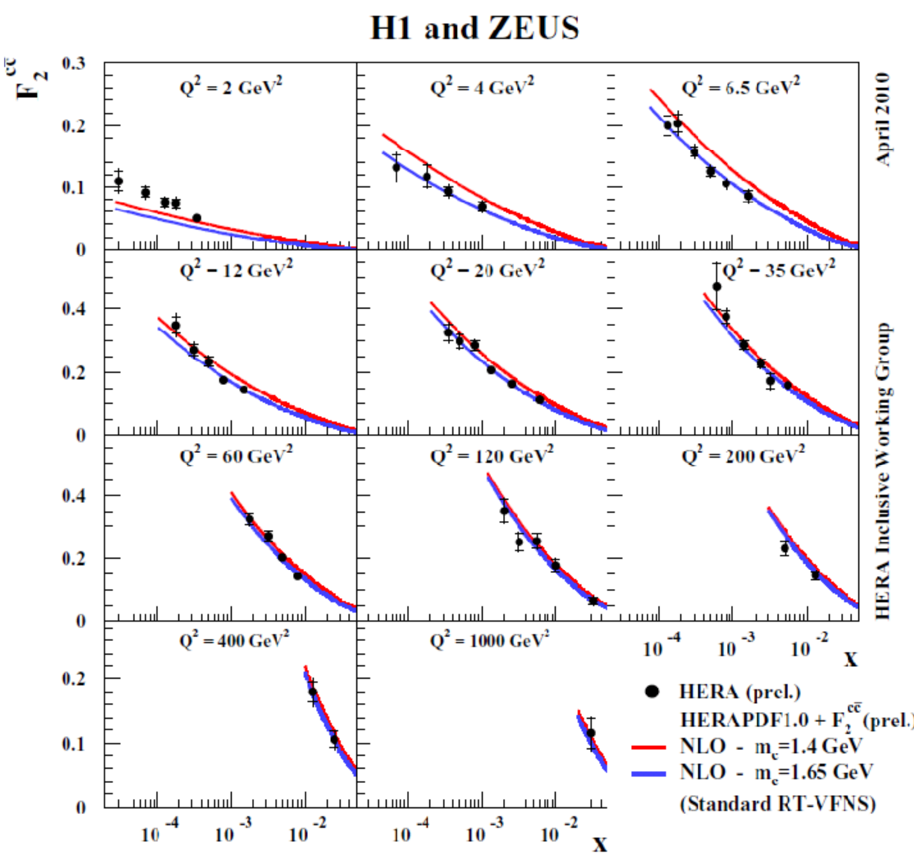
We do this again including F_2(charm) data using both values of charm mass.

The ACOT fit prediction is very similar to the RT Standard prediction and the fit also prefers the larger value of charm mass m_c=1.65 GeV

ACOT VFN (full)



Standard RT VFN



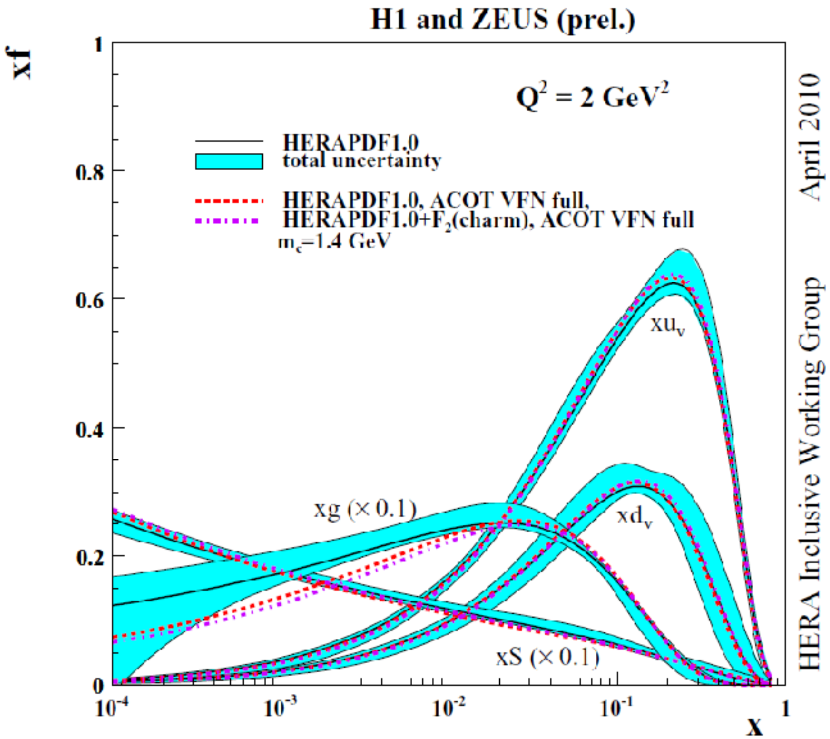
χ^2 for the F_2(charm) data is MUCH better for mc=1.65 for RT VFN Standard

χ^2 for the F2(charm) data is MUCH better for mc=1.4 for RT VFN Optimized

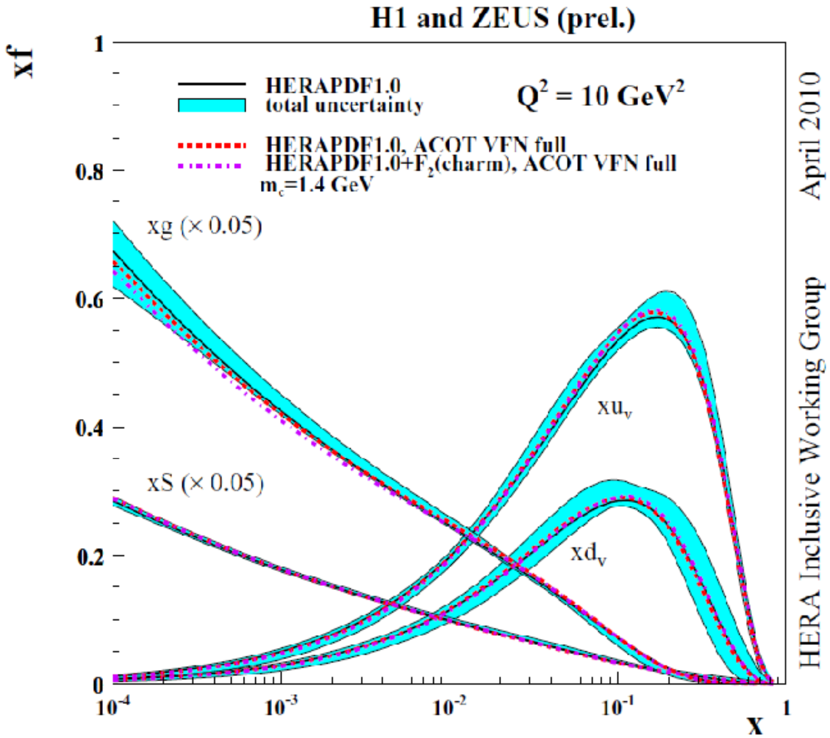
χ^2 for the F2(charm) data is MUCH better for mc=1.65 for ACOT VFN full

scheme	RT Std m_c=1.4	RT Std m_c=1.65	RT Opt m_c=1.4	RT Opt m_c=1.65	ACOT m_c=1.4	ACOT m_c=1.65	#points
χ^2	730.7	627.5	644.6	695.4	653.9	605.7	633
$F_2^{(charm)}$ Sub χ^2	134.5	43.5	64.8	100.1	89.5	41.4	41

Now compare the PDFs for the ACOT VFN and Standard RT VFN Schemes



At the starting scale



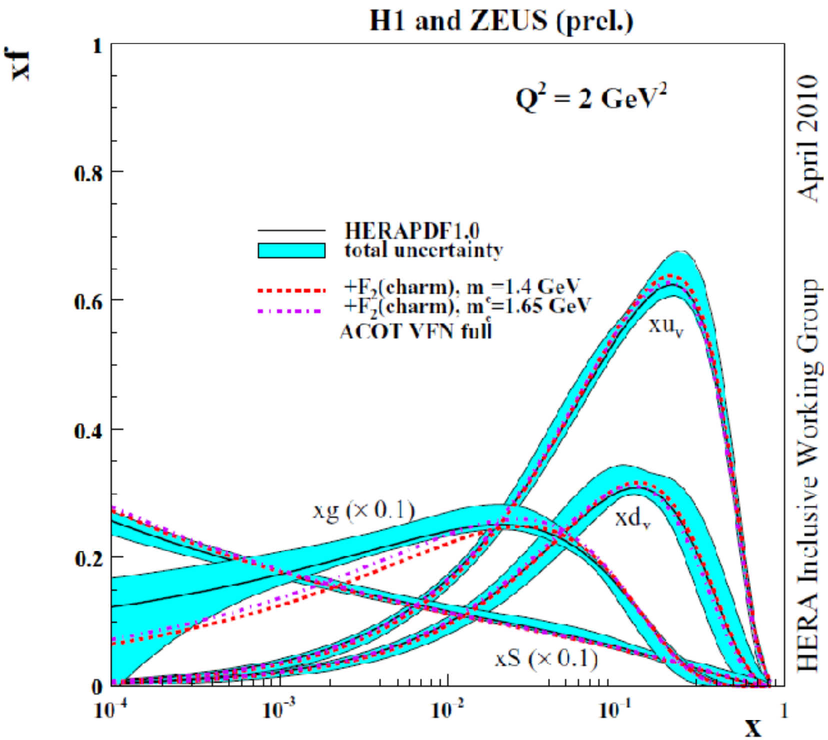
At Q^2=10 GeV^2

Compare an ACOT VFN fit to just HERA-I inclusive data to an ACOT VFN fit to HERA-1 inclusive +F_2(charm) data

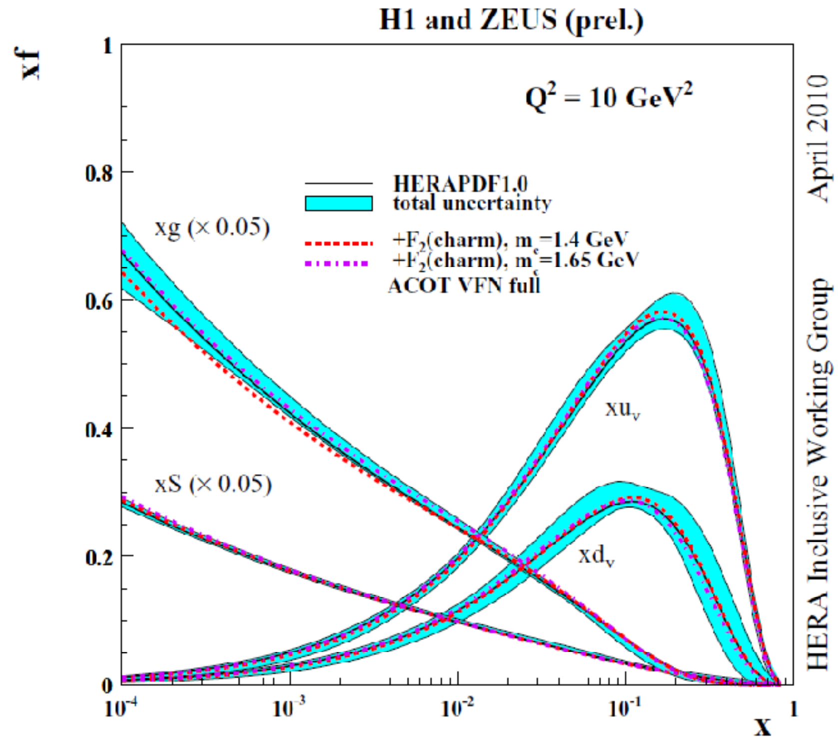
These are very similar BUT ACOT gluon shape is suppressed compared to the Standard RT VFN scheme used for HERAPDF1.0

Illustrations are made at the central value m_c=1.4 GeV

Now compare the PDFs for the ACOT VFN and Standard RT VFN Schemes



At the starting scale



At Q^2=10 GeV^2

And this compares ACOT VFN fits to HERA-1 inclusive +F2(charm) data using m_c=1.4 GeV and m_c=1.65 GeV. The fit prefers m_c=1.65 GeV

Now TRY Fixed Flavour Number fits

These are needed because HVQDIS which is used to extract F_2 (charm) from D* production uses FFN

However we CANNOT fit Charged Current data – no readily usable FFN NLO coefficient functions are available for F_2 or xF_3 and although the scale is high for HERA CC data one cannot just use Zero Mass VFN for CC- the problem is that there is no charm PDF and so the process W+c →s is missing and no coefficient function is making up for this!

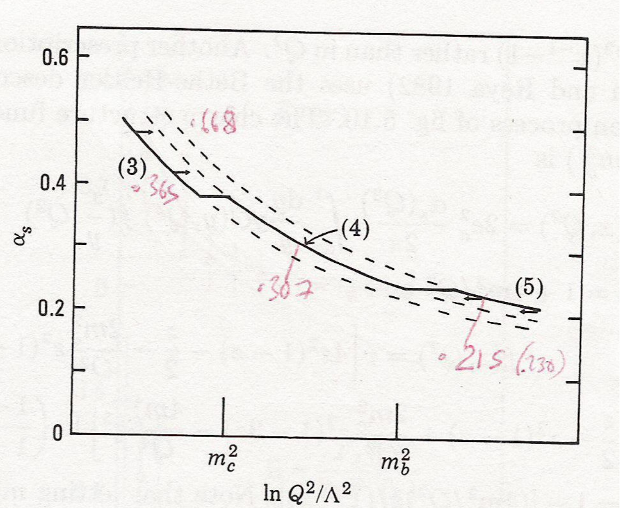
Thus we leave Charged Current data out: 633 data points down to 565
(Could also restrict $Q^2 < 3000$ GeV^2 because not resumming $\ln(Q^2/mc^2)$-but this makes little difference)

Fit σ NC e+ (379), NC e-(145) and F2c (41)

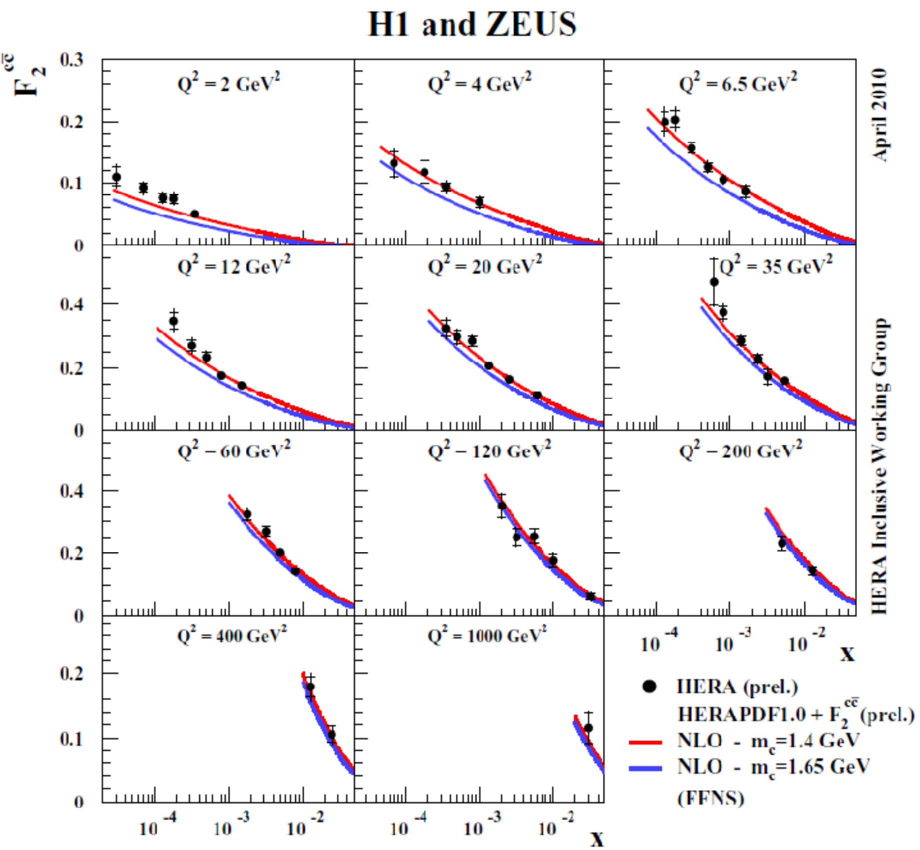
Hence FIX valence parameters- but try extra Sea/gluon parameters -no significant difference

USE heavy quark factorisation scale $Q^2+4m_c^2$
(but using Q^2 makes little difference)

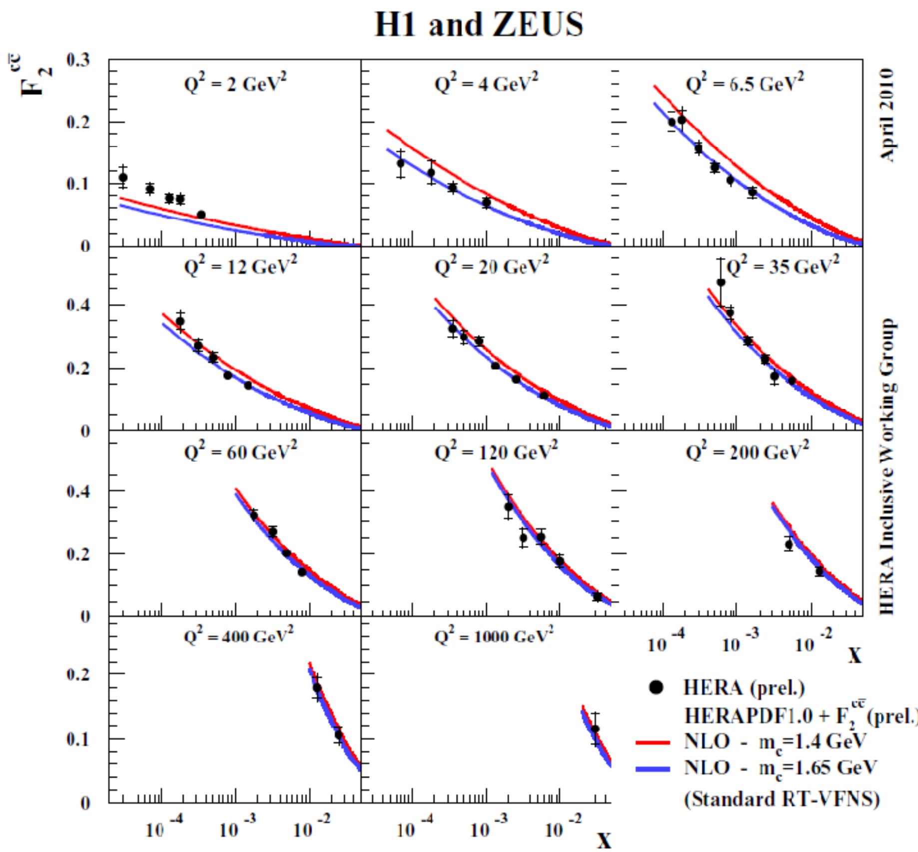
USE 3-flavour $\alpha_S(Q^2)$ so $\alpha_S(M_z^2)$ must be set low (0.105) so that it is not too high at low energy



FFN



Standard RT VFN



Compare FFN fit with STANDARD RTVFN fit

FFN is relatively suppressed (even more so than OPTIMAL RT VFN)

Hence FFN does not need a larger value of m_c to suppress the F_2(charm) predictions- data prefer m_c=1.4GeV

$\chi 2$ for the F_2(charm) data is MUCH better for mc=1.65 for RT VFN Standard

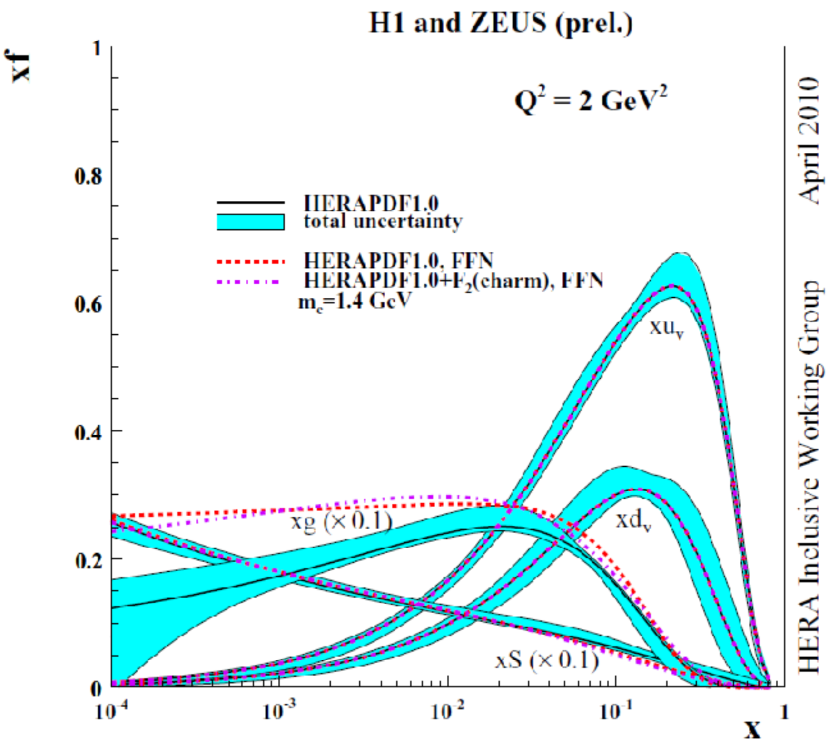
$\chi 2$ for the F2(charm) data is MUCH better for mc=1.4 for RT VFN Optimized

$\chi 2$ for the F2(charm) data is MUCH better for mc=1.65 for ACOT VFN full

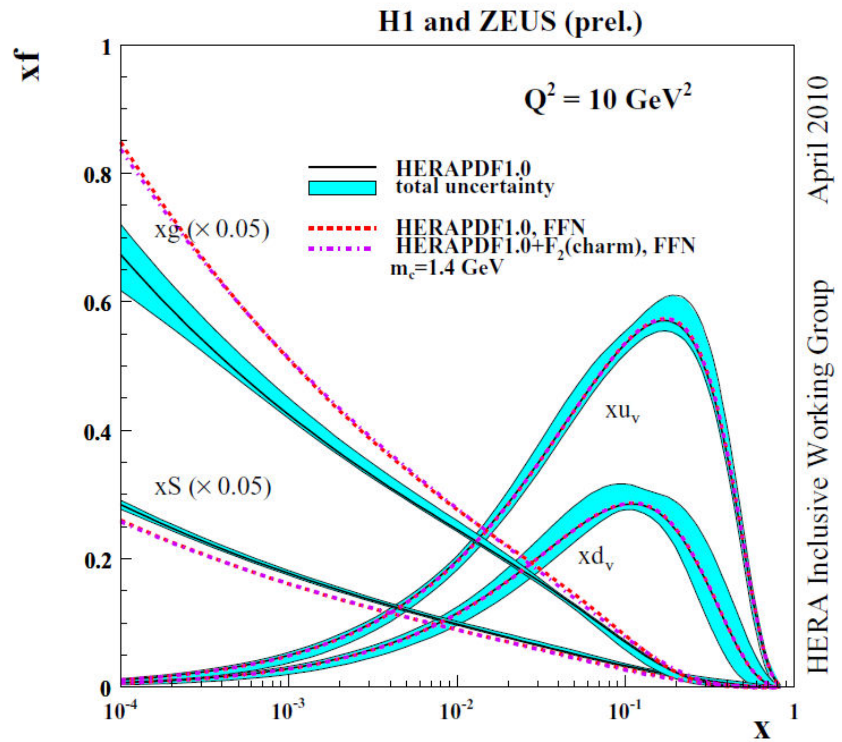
$\chi 2$ for the F2(charm) data is VERY MUCH better for mc=1.4 for FFN

scheme	FFN m_c=1.4	FFN m_c=1.65	#points		FFN m_c=1.4 no F_2^c	#points
$\chi 2$	**567.0**	**852.0**	565		512.9	524
$F_2^{(charm)}$	51.7	248.9	41			0

Now compare the PDFs for the FFN and Standard RT VFN Schemes



At the starting scale



At Q^2=10 GeV^2

Compare an FFN fit to just HERA-I inclusive data to an FFN fit to HERA-1 inclusive +F_2(charm) data

These are very similar BUT the FFN gluon shape is VERY different from that of the Standard RT VFN scheme used for HERAPDF1.0

Note the difference in the Sea at this scale is just due to there being no charm quark

Illustrations are made only for m_c=1.4 GeV since the χ2 for m_c=1.65 GeV is very poor

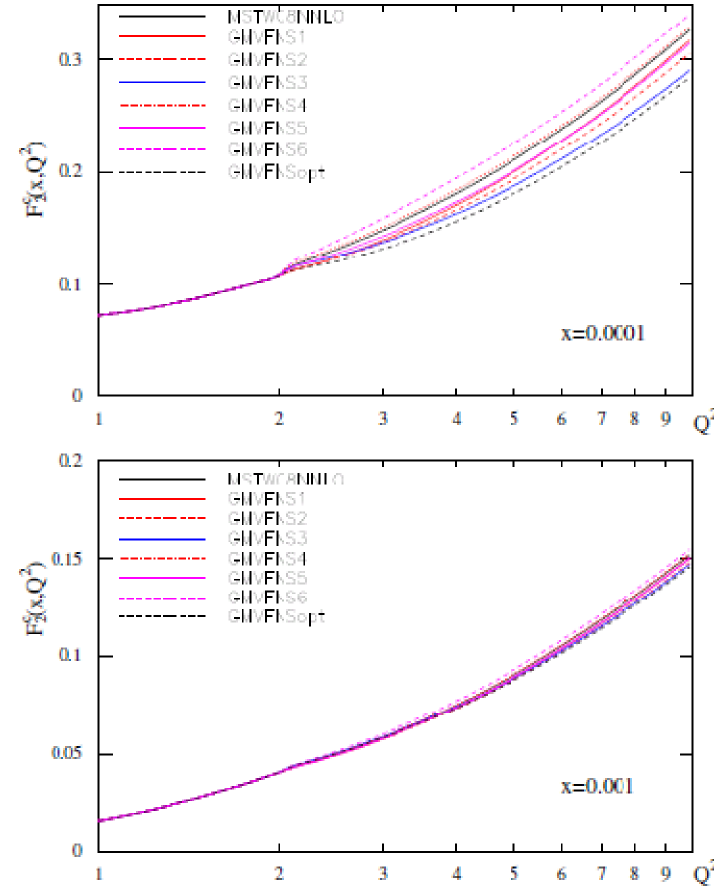
And lastly NNLO fits to F_2(charm)

For this we will use the Standard RT VFN scheme at NNLO.

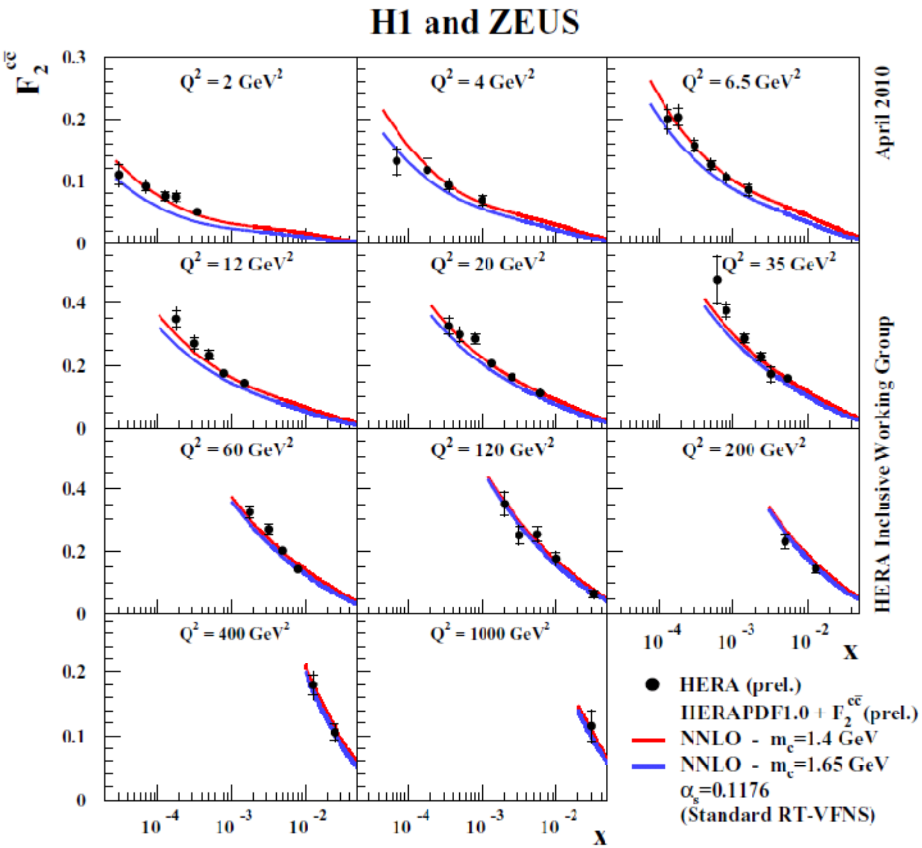
Variations of schem are considerably reduced at NNLO

We have considered an NNLO version of HERAPDF1.0 fit using just HERA-1 data for two different values of $\alpha_s(M_Z)$= 0.1176, 0.1145 as reported in the talk of Radescu in PDFs Session-1

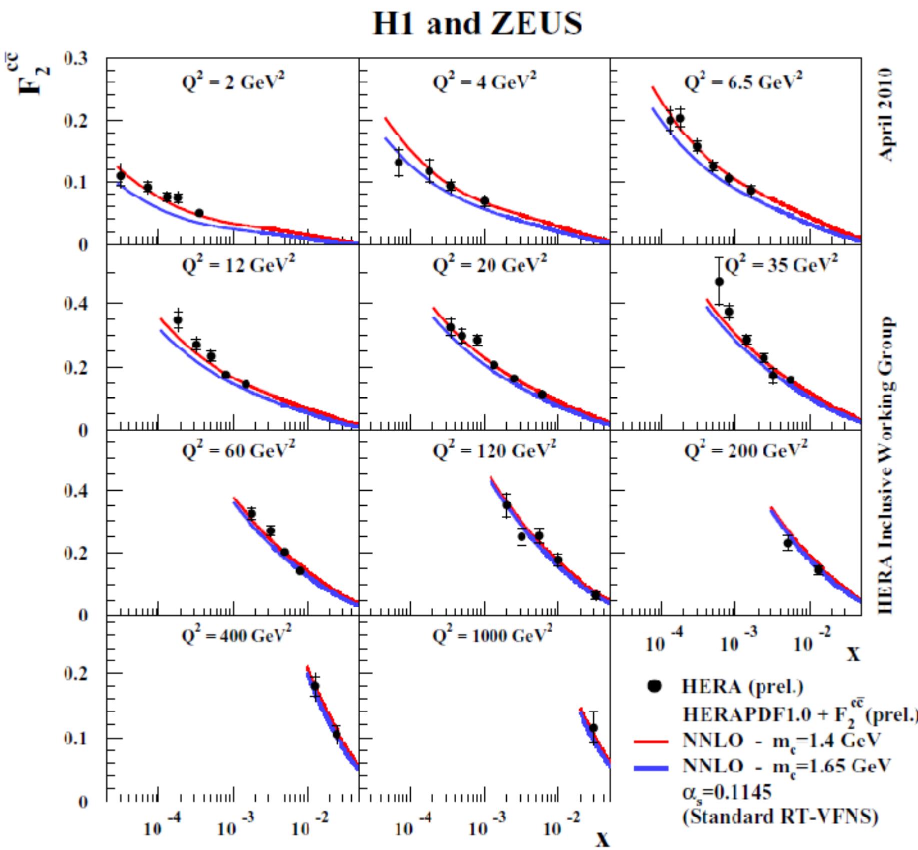
Then we have considered adding the F_2(charm) data and values of the charm mass m_c=1.4, m_c=1.65 GeV



NNLO $\alpha_s(M_Z)$ =0.1176



NNLO $\alpha_s(M_Z)$=0.1145



The shape of the NNLO fits describes the data well- even down to Q^2=2 GeV^2

The NNLO fits with F_2 (charm) have better χ2 for m_c=1.4 GeV (strong preference) and $\alpha_s(M_Z)$=0.1145 (MILD preference)

The value of α_s is NOT so crucial – the fit parameters re-adjust to give similar predictions- But the value of the charm mass is important

$\chi 2$ for the F2(charm) data is MUCH better for mc=1.4 for NNLO

$\chi 2$ for the all the data is better for $\alpha_s(M_Z)$=0.1145 for NNLO

The NNLO $\chi 2$ are not as good as the NLO $\chi 2$ for the inclusive data (Q^2> 3.5 GeV^2)

A comparison is also made to an NNLO fit without charm data (see also the talk of V. Radescu)

scheme	NNLO α_s=0.1145 m_c=1.4	NNLO α_s=0.1145 m_c=1.65	NNLO α_s=0.1176 m_c=1.4	NNLO α_s=0.1176 m_c=1.65	#points	NNLO α_s=0.1145 m_c=1.4 no F_{2c}	#points
$\chi 2$	**681.1**	**832.9**	**703.1**	**862.3**	633	653.9	592
$F_2^{(charm)}$	54.5	185.7	60.3	198.0			

CONCLUSIONS

Addition of charm data to the fits does not change the PDFs or the $\chi 2$ of the other data significantly. BUT

Charm data are sensitive to the charm mass and the heavy quark scheme. Any hope to reduce model dependence of PDFs due to the choice of charm mass is defeated by theoretical uncertainty from choice of scheme:

AT NLO:

- Standard RTVFN fits to F_2 (charm) prefer m_c=1.65 GeV
- Optimal RTVFN fits to F_2(charm) prefer m_c=1.4 GeV
- ACOT VFN full fits to F_2(charm) prefer m_c=1.65 GeV
- FFN fits to F_2(charm) prefer m_c=1.4 GeV

Since all schemes are valid there is substantial theoretical uncertainty

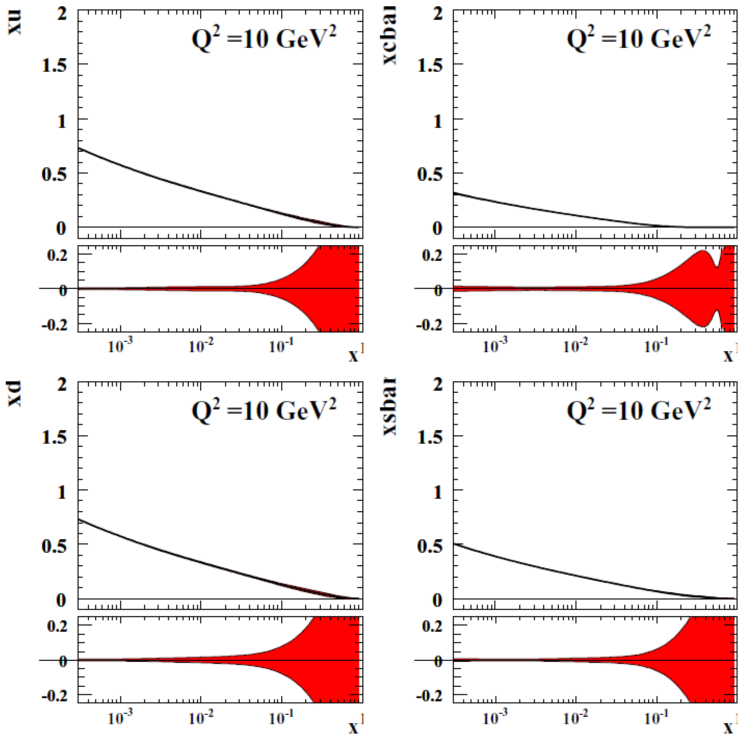
FURTHERMORE the value of the charm mass is not insignificant for predictions for the W/Z cross-section at the LHC

NNLO fits to F_2(charm) with m_c=1.4 GeV describe the transition down to Q^2=2 GeV^2 very well AND scheme dependence is reduced at NNLO

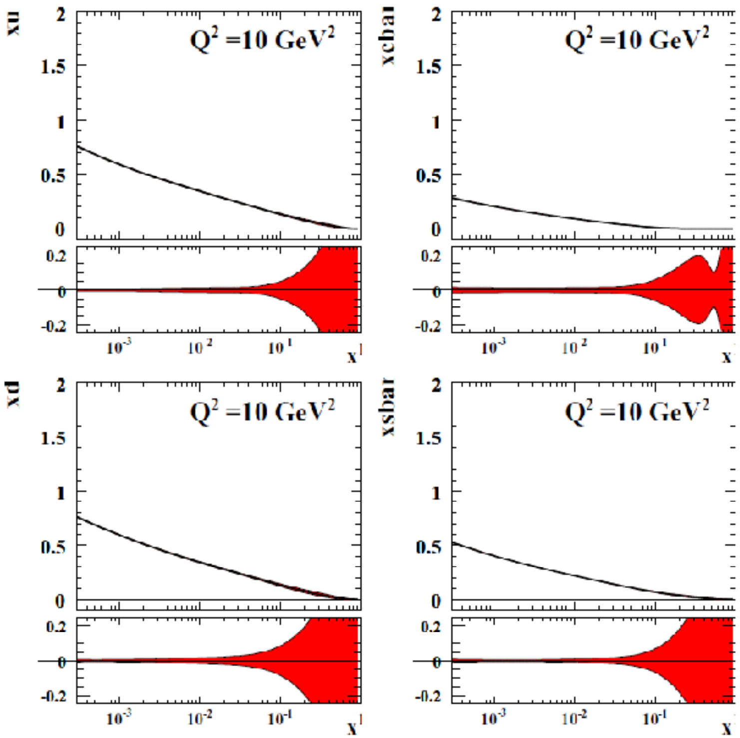
extras

Does the F2charm data improved the uncertainties on the PDFs?

Compare experimental PDF uncertainty bands. I can see a marginal decrease in the size of the cbar uncertainty- encouraging



HERAPDF1.0



HERAPDF1.0 plus F2charm

However model uncertainties due to the choice of charm mass can be larger and there is signiciant variation in the choice of scheme for heavy flavour treatment